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HIGH INTEGRITY CUPRO-NICKEL CASTINGS FOR TECHNOLOGY DEMONSTRATION AND SEA-WATER SERVICE EVALUATION

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HIGH INTEGRITY CUPRO-NICKEL CASTINGS FOR TECHNOLOGY DEMONSTRATION AND SEA-WATER SERVICE EVALUATION

by

M. Sahoo and J.O. Edwards

ABSTRACT

This report deals with the manner in which the Cu-Ni technology developed at PMRL/CANMET was transferred to a Canadian Foundry where two ship's sets, each of eight castings, were produced in 90/10 and 70/30 Cu-Ni alloys.

INTRODUCTION

Copper castings for marine service are traditionally made from tin bronzes because of their excellent corrosion resistance and other desirable properties. These alloys are, however, very prone to shrinkage porosity which reduces the mechanical properties of the castings themselves (as opposed to separately cast test-bars), and results in large variations in properties between castings. Consequently, there is concern about the reliability of the individual castings; particularly in shock-loading conditions in naval vessels.

In response to this need for improved materials, PMRL/CANMET, supported by DND-CRAD, has investigated the foundry characteristics and mechanical properties of high-strength cupro-nickels (1). The Canadian foundry industry has been made aware of this through talks and demonstrations during a copper-alloy foundry "workshop" (technology-transfer seminar) held at PMRL during September 1979.

As a practical sequel to this earlier work, DND-CEM requested that we should provide technical support to obtain from Canadian sources two ship's sets, each of 8 large cast manifolds, in niobium-modified 90/10 and 70/30 cupro-nickels. These would replace existing castings and, at the same time, would enable a comparative evaluation of the performance of the two Cu-Ni alloys under service conditions.

A number of leading bronze foundries provided quotations on production of the castings and finally a contract was placed with Burnstein Castings Ltd., St. Catherines, Ontario. The object of the contract was (a) to supply a strategic need from Canadian sources and (b) to upgrade the technological capability of the Canadian foundry industry.

DESCRIPTION OF THE CASTINGS

DND supplied the production drawings and patterns from SK 2754 to SK 2759.

As can be seen from the photographs of the patterns in Figs. 1(a) to (g), the castings are essentially elbows of several different orientations with one or two large inlets and four smaller outlets. Despite the fact that the elbow castings appear very similar, a small angular difference in the pattern design can markedly change the moulding method and the way the

pattern is withdrawn from the mould. The physical lay-out of the pattern and the moulding method in turn have a major influence on gating and risering, depending on the accessibility of the different parts of the casting at the parting line and top of the mould.

Two castings, one each in 90/10 and 70/30 Cu-Ni, were produced from each pattern, except SK 2756 which called for four castings, two each in 90/10 and 70/30 Cu-Ni.

The requirements for these castings were:

(a) air-pressure test at 50 psi (345 kPa) before machining,

(b) radiographic inspection to level 2 of ASTM E272(2),

(c) proof (water) pressure-test at 400 psi (2760 kPa) after machining,

(d) composition limits and mechanical properties of separately cast test-bars conforming to ASTM B369-78 (5) for alloys C96200 (90/10 Cu-Ni) and C96400 (70/30 Cu-Ni).

EXPERIMENTAL PROCEDURE

Melting was carried out in a lift-coil induction furnace using 210 lb (95 kg) capacity clay-graphite crucibles, coated with zircon. The graphite or steel rods used for stirring or plunging alloying elements were also coated with zircon. All melts were conducted under an oxidizing atmosphere using Cuprex flux. Foseco Slax-30B slag coagulant was used to thicken the flux residues to aid skimming and prevent slag entrainment in the metal stream.

The charge consisted of pre-alloyed 70/30 Cu-Ni ingots; "in-house" scrap consisting of runners, gates and risers which were clean and reasonably free of sand; and electrolytic Mn. Si and Nb were added as Si-Fe and Nb-Fe master alloys containing respectively 95% Si and 55% Nb.

Melts of 90/10 Cu-Ni were made from the same base using the same techniques but enough electrolytic tough-pitch copper and master alloys was added to produce the 90/10 composition from the 70/30 base.

The melts were produced by charging the crucible with Cu-Ni ingots, and both scrap and pure Cu, and then heating under full power to 1300 and 1400°C (2370 and 2550°F) for 90/10 and 70/30 Cu-Ni respectively. Cuprex flux weighing about 500 g was spread after the charge started to melt. When the required temperature was reached, manganese, ferro-silicon and ferro-niobium were added to the melt followed by the spreading of 450 g of Slax-30B. The

melt was then deoxidized by plunging one Foseco NS No.6 deoxidizing tube weighing 84 g. After skimming the Slax cover, the crucible was transferred to the pouring area. Before pouring, the melt was desulphurized by adding 250 g of magnesium. The pouring temperature was about 1250 and 1350°C (2300 and 2450°F) for the 90/10 and 70/30 Cu-Ni melts respectively.

The reduced-pressure gas-test conducted on site indicated a very low gas content for the melts (3). The time taken for melting and casting was about 70 min. The castings were allowed to cool in the moulds for at least 2h before being shaken out.

CO_2 moulds and oil cores (baked) were used for all the castings. The moulding time varied from 2 to 4h depending on the casting design. Similarly the time to make the core was about 2 - 3h. In addition the cores were baked twice, 3.5h each time at a temperature of 230°C (450°F). The cores were usually vented. The cope and drag box size was 36 x 24 in. (914 x 610 mm). The drag and cope heights varied between 6 and 8 in (152 and 203 mm) depending on the flange diameter. This is also reflected in the variation in the sprue height as shown in Table 1.

RESULTS AND DISCUSSION

CHEMICAL ANALYSIS

As shown in Table 2, all the melts generally conformed to the composition limits for alloy C96200 (90/10 Cu-Ni) and C96400 (70/30 Cu-Ni) specified in ASTM B369-78 (5) with the following exceptions:

(i) The iron content of each of the 90/10 melts was below the specified minimum. Iron is added to improve the impingement/corrosion-resistance and to refine the grain.

(ii) The silicon content of melt No. 11 was slightly above the specified maximum.

GATING SYSTEM

In each case a tapered sprue with a sump at the bottom was used and molten metal was poured into the pouring basin. The gating system for each casting is given in Table 1 and can be seen in the various figures. Dross traps were used at the ends of runners.

The 90/10 Cu-Ni alloys have a freezing range of 20C° (36F°) and can be classified as short freezing-range alloys. However, the 70/30 Cu-Ni alloys have a solidification range of 50C° (90F°) and are likely to show fine interdendritic shrinkage. Hence, it was decided to confine the trial runs to 70/30 Cu-Ni alloys to develop the gating and risering systems. To this end, attention was focused on the representative castings SK 2754 containing a single flange and SK 2757-2 containing two flanges.

The aim was to use an unpressurized system with a gating ratio of 1:2:3 and a pouring rate of ~4.5 lb/sec (2 kg/sec). However, for the gating system shown in Figs. 2 and 3 and Table 1 (melts 1 and 2), the pouring basin was never full and the mould filled too quickly. The high flow rate for this sprue size was unusual for offset pouring boxes, and considered to be a dynamic effect of pouring directly into the sprue in the foundry; consequently the sprue cross-sectional area was reduced. To improve the hot metal distribution, runners were placed on both sides of the casting, and all gating was through the side risers (Figs. 5, 6, 8-12). This also helped to reduce the velocity of metal flow into the casting because more than two gates were used. To obtain a uniform metal flow through the gates, the runner cross-section was reduced by the area of each gate passed. In addition, the following precautions were taken:

(i) Junctions between sprue and runner and between sprue well and runner was radiused to streamline the flow.

(ii) Sharp bends in the runner system was avoided (Figs. 9-12).

(iii) Dross traps were used at the ends of runners, with a volume equal to that of the sprue well.

RISERING SYSTEM

The procedures used in designing a risering system have been described in detail elsewhere (8). An important relation between thickness T, and feeding distance D, is

$$D = 5.8\sqrt{T} \qquad (1)$$

This equation is used to decide the number of risers to be used. When this is established, riser size is determined by the NRL method developed by Pellini et al (7). To facilitate the calculation of riser size, each casting was divided into a number of sections, e.g., flange, nozzles, body, mounting

legs etc. and the riser size for each section was calculated separately. The short feeding distance for the Cu-Ni alloys (3-5 in. or 76-127 mm) warranted the use of chills at a number of locations to minimize the influence of unfeedable hot spots. This also helped to increase the casting yield significantly. The calculations showed that cylindrical risers, 2.5 in (63 mm) diam x 4 in (102 mm) high, could provide adequate feeding. To limit the riser height to 4 in (102 mm), blind risers were used in most cases. Foseco insulating sleeves were used for all the risers. The top of the blind riser was layered with exothermic compound and core sand. After pouring, the open risers were covered with Foseco topping to reduce the rate of heat loss.

Cast iron chills where used were located ¼ in (6 mm) below the mould surface to eliminate "chill blows". The dimensions for the chills were 1½ x 1 x 1 in (38 x 25 x 25 mm) for the flanges (drag half only), 1 x 1 x 3/4 in (25 x 25 x 19 mm) for the nozzles and 2 x 2 x 1 in (51 x 51 x 25 mm) for the square flanges (castings SK 2757-1 and -2) and mounting legs (SK 2754 and SK 2759). Chilling of the nozzles was further enhanced by the use of chromite sand in the cores in this area. Nozzles connected to risers were not chilled and the chromite was graded to keep feeding channels open.

The risering systems for each of these castings are described in Table 3 and can be seen in the various figures.

CASE STUDIES

1. Casting SK 2754 and SK 2759

For the risering system shown in Fig. 1 and Table 3 (melt No. 1) for casting SK 2754, the major defects revealed by X-ray radiographic analysis were random inclusions of slag and gas and/or shrinkage porosity (> level 5) in the junction between the flange and the body in the area away from the side riser (Figs. 2 and 4). There was some shrinkage in the junction of the square mounting legs and the body, and in the nozzle-body junctions in the side opposite to the nozzle risers.

The following steps were taken to minimize the above defects.

(i) Core venting was increased to reduce gas porosity from this source,

(ii) Another blind riser was added to the flange to improve feeding,

(iii) Chilling on the square mounting legs and the circular flange was increased,

(iv) In the nozzles, which were connected to the risers, the height of the chromite-sand chilling in the cores was increased on the side away from the riser,

(v) An open riser was added to the body to improve feeding,

(vi) Sprue, runners, and gates were modified as discussed to achieve lower flow rates (thus reducing gas and dross inclusions), and a better hot metal distribution thus increasing the riser effectiveness.

Utilizing such revised gating and risering systems (Fig. 5), class 2-type castings were obtained in both 90/10 and 70/30 Cu-Ni alloys. Very little microporosity was observed in the junctions of the square mounting legs and the body. Similar gating and risering systems were used for casting SK 2759 to produce class 2 type castings in both 90/10 and 70/30 alloys (Fig. 6).

2. Casting SK 2757-2 and SK 2757-1

For the gating and risering system shown in Fig. 3, the major defects for casting SK 2757-2 as indicated in Fig. 7(a) and (b) were:

(a) a number of isolated inclusions of slag,

(b) severe shrinkage porosity (> level 5) at the junctions of flange and body for the flange which had only one riser (see Fig. 3),

(c) shrinkage porosity at the junctions of the body and the square mounting flange, and between the two square mounting flanges, and in the area behind the single riser on the flange.

The following steps were taken to minimize the above defects:

(i) The pouring rate was reduced by increasing the choke at the sprue exit and the metal velocity was reduced by increasing the number of gates. This allowed more time for the mould and core gases to escape.

(ii) The core venting was increased.

(iii) The feeding was increased by adding a riser to the flange which had only one riser.

(iv) A small top riser was added to the body in the region of the square mounting flange.

(v) Hot metal distribution was improved by running it down both sides of the casting and by gating into all four flange risers.

(vi) Chilling on the circular and square mounting flanges was increased.

These modifications (Fig. 8) improved the casting quality in the 90/10 alloy (melt No. 5) and shrinkage porosity was reduced to level 2.

There was very little microporosity between the square mounting flanges or between the body and the circular flange junctions in the cope half. However, in the case of the 70/30 alloy (melt No. 4), although the overall casting quality was much improved, shrinkage porosity (level 4) was still observed between the body and the circular flanges (cope half) and between the body and the square mounting flanges.

To improve further the quality of the 70/30 casting, two changes were considered. The first was to add one riser to the top of the body to feed the square mounting flange, and another at the nozzle to feed the nozzle-flange area. This would provide local feed metal but would unfortunately reduce the overall thermal gradient. The second was to increase chilling of all flanges to increase the thermal gradient. The first modification was chosen for convenience and flexibility. This modified risering system (Fig. 9) improved the casting quality to level 1 in the circular flanges and to level 2 in the body. There was still some shrinkage in the area between the two square mounting flanges.

The gating and risering system shown in Fig. 9 for casting SK 2757-2 was used to produce casting SK 2757-1 in both 90/10 (melt No. 16) and 70/30 (melt No. 12) Cu-Ni alloys. In both alloys the flanges were classified by radiography as level 2 and the body with the nozzles as level 1. There was some shrinkage in the area between the body and the square mounting flanges near the riser location. This shrinkage was classified as level 3 in the case of the 70/30 alloy. However, the casting passed the 400 psi (2750 kPa) water-pressure test.

3. Castings SK 2755, 2756 and 2758

The gating and risering systems for these castings are summarized in Tables 1 and 3 and shown in Figs. 10, 11 and 12. All the castings passed the pressure test and met the ASTM radiographic requirements except the 70/30 castings SK 2755 and SK 2756 which had slag inclusions and some shrinkage in the cope half of the flange below the top riser. However, these were not considered to be serious and could be repaired by welding.

MICROSTRUCTURE

Typical optical micrographs of the 90/10 and 70/30 Cu-Ni alloys, obtained from the test-bar castings, are shown in Fig. 13(a) and (b).

Fig. 13(b) shows vein-like silicide precipitates in the inter-dendritic areas. There are none in 90/10 alloys probably because of the low silicon content. An interesting feature of the 90/10 alloys is the presence of some faceted phases. Electronprobe microanalysis showed these phases to be rich in Si, Nb, Ni, and to include some Cu.

TENSILE PROPERTIES

Tensile properties of the test-bar castings are summarized in Table 4. All the melts met the requirements for mechanical properties of alloys C 96200 and C 96400 specified in ASTM B369-78.

Tensile properties of specimens removed from relatively sound portions of one of the flanges in casting SK 2757-2 (melt No. 4) are also included in Table 4. This table shows that the tensile properties of the sound areas conform to ASTM B 369-78. However, the yield strength is slightly high and hence, the tensile elongation is low with respect to separately cast test bars. This is to be expected because the diameter and gauge length of the tensile specimen machined from the flange were smaller than standard.

SUMMARY AND CONCLUSIONS

1. The Cu-Ni technology developed at PMRL has been successfully transferred to a Canadian foundry where two ship's sets of eight castings each were produced in niobium-modified 90/10 and 70/30 Cu-Ni alloys. All the 16 castings met the 400 psi (2760 kPa) pressure-test and the mechanical properties specified in ASTM B369-78. In addition all were judged to meet the ASTM radiography requirements either in toto, or at least in the critical areas.
2. The hot metal distribution was improved by using an unpressurized gating system and by gating into most of the side risers. The measured pouring rate varied from 5-8 lb/sec (2.3-3.6 kg/sec).
3. The average casting yield was of the order of 50% due to the use of insulated blind risers and chills. Optimization of casting yield was not attempted because of time limitations to produce the castings.

4. For similar gating and risering systems, the casting quality was better in the short freezing range 90/10 alloys. In the 70/30 alloys of intermediate freezing range, some porosity was produced in areas of low thermal gradient.

5. Technically the project represents a successful transfer of laboratory experience to a commercial Canadian foundry, and also a reverse flow of practical, foundry experience into the laboratory, to the mutual benefit of both.

6. Commercially, the project represents a considerable achievement in that 16 fully-machined high-technology castings, in alloys not widely used and to requirements not widely quoted, were obtained from Canadian sources at competitive cost. That this was achieved in only six months from original concept is a measure of the co-operation exhibited by all parties, and particularly the foundry management.

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Table 1. Gating systems and pouring rates for 90/10 and 70/30 Cupro-Nickel

Melt No.	Drawing No.	Fig. No.	Type of melt	Sprue height* in (mm)	Sprue exit cross section in (mm)	Runner cross section in (mm)	Gate cross section in (mm)	Gating ratio (sprue: runners: gates)	Casting weight lb (kg) before fettling	Casting weight lb (kg) after fettling	Casting yield** %	Mould filling time, sec.	Flow rate lb/sec (kg/sec) Actual	Flow rate lb/sec (kg/sec) calculated Ref. 4	Radiographic acceptance standard+
1	SK 2754	2	70/30	9 (229)	1x3/4 (25x19)	1x3/4 (25x19)	1½x3/4 (38x19)	1:2:3	110 (50)	74 (33.6)	67	13	8.5 (3.9)	10 (4.5)	- not accepted - > level 5
2	SK 2757-2	3	"	"	1x3/4 (25x19)	1x3/4 (25x19)	1½x3/4 (38x19)	1:2:3	132 (60)	80 (36.3)	61	12	11 (5)	10 (4.5)	- not accepted - > level 5
3	SK 2754	5	"	"	5/8 dia (16)	1x1+1x½ (25x25)+ (25x13)	1x½ (25x13)	1:6:6	136 (61.7)	74 (33.6)	54	27	5 (2.3)	4 1.8	- accepted - level 2
4	SK 2757-2	8	"	"	5/8 dia (16)	"	"	1:6:6	136 (61.7)	80 (36.3)	59	29	5.3 (2.3)	4 1.8	- not accepted - level 4
7	SK 2758	12(a)	"	11 (279)	5/8 dia (16)	"	"	1:6:6	184 (83.5)	84 (38.1)	46	34	5.4 (2.4)	4.5 (2)	- accepted - level 1&2
10	SK 2759	6	"	9 (229)	5/8 dia (16)	"	"	1:6:6	135 (61.3)	70 (31.8)	52	32	4.2 (1.9)	4 (1.8)	- accepted - level 2
11	SK 2756	11(a)	" "	13 (330)	½ dia (13)	"	"	1:9:7	147 (66.7)	76 (34.5)	52	27	5.4 (2.4)	3 (1.4)	- accepted - level 1&3
12	SK 2757-1	9	"	9 (229)	3/4 dia (19)	"	"	1:4:4	165 (74.9)	80 (36.3)	48	21	7.8 (3.5)	5.8 (2.6)	- accepted - level 1,2&3
13	SK 2756	11(b)	"	13 (330)	5/8 dia (16)	"	"	1:8:5	137 (62.2)	76 (34.5)	55	22	6.2 (2.8)	4.8 (2.2)	- accepted - level 1&4
14	SK 2755	10	"	13 (330)	5/8 dia (16)	"	"	1:4:8	192 (87.2)	100 (45.4)	52	25	7.7 (3.5)	4.8 (2.2)	- accepted - level 1&3
15	SK 2757-2	9	"	9 (229)	3/4 dia (19)	"	"	1:4:4	168 (76.3)	80 (36.3)	48	20	8.4 (3.8)	5.8 (2.6)	- accepted - level 1&2
5	SK 2757-2	8	90/10	9 (229)	5/8 dia (16)	"	"	1:6:6	150 (68.1)	81 (36.8)	54	27	5.6 (2.5)	4 (1.8)	- accepted - level 2&3
6	SK 2754	5	"	9 (229)	5/8 dia (16)	"	"	1:6:6	134 (60.8)	78 (35.4)	58	24	5.6 (2.5)	4 (1.8)	- accepted - level 1
8	SK 2758	12(b)	"	11 (279)	5/8 dia (16)	"	"	1:6:6	180 (81.7)	82 (37.2)	46	33	5.4 (2.4)	4.5 (2)	- accepted - level 1&2
9	SK 2759	6	"	9 (229)	5/8 dia (16)	"	"	1:6:6	135 (61.3)	70 (31.8)	52	26	5.2 (2.4)	4 (1.8)	- accepted - level 1&2
16	SK 2757-1	9	"	9 (229)	3/4 dia (19)	"	"	1:4:4	168 (76.3)	81 (36.8)	48	21	8.0 (3.6)	5.8 (2.6)	- accepted - level 1&2
17	SK 2755	10	"	13 (330)	5/8 dia (16)	"	"	1:4:8	206 (93.5)	100 (45.4)	49	24	8.6 (3.9)	4.8 (2.2)	- accepted - level 1&2
18	SK 2756	11	"	13 (330)	5/8 dia (16)	"	"	1:8:5	145 (65.8)	76 (34.5)	52	21	6.9 (3.1)	4.8 (2.2)	- accepted - level 2
19	SK 2756	11	"	13 (330)	5/8 dia (16)	"	"	1:8:5	142 (64.5)	76 (34.5)	53	20	7.1 (3.2)	4.8 (2.2)	- accepted - level 2

*Including pouring basin. All sprues tapered @ 3°.

**% Yield = $\frac{\text{Wt. after fettling}}{\text{as-cast wt.}} \times 100$

+See Table 3 for details

Table 2. Chemical analysis of 90/10 and 70/30 Cu-Ni alloys.

Melt No.	Drawing No.	Type of melt	Elements, wt%									
			Cu	Ni	Fe	Mn	Si	Nb	Pb	S	C	Mg
5*	SK 2757-2	90/10 Cu-Ni	87.4	9.75	0.53	1.18	0.15	0.62	0.01	0.01	0.002	
5	SK 2757-2		88.2	9.7	0.48	1.15	0.16	0.18	0.007			
6	SK 2754		88.24	9.65	0.49	1.1	0.17	0.18	0.04			
8	SK 2758		87.61	10.0	0.79	1.06	0.14	0.32	0.009			
9	SK 2759		87.69	9.9	0.9	0.94	0.12	0.32	0.03			
16	SK 2757-1		87.63	9.95	0.55	1.14	0.21	0.35	0.02			
17	SK 2755		87.67	9.9	0.68	1.16	0.16	0.27	0.015			
18	SK 2756		87.87	9.9	0.53	1.12	0.15	0.24	0.025			
18	SK 2756*		87.4	10.7	0.38	1.04	0.18	0.76	0.01	-	-	0.035
19	SK 2756		87.8	9.95	0.56	1.14	0.19	0.20	0.025			
ASTM B369-78 limits for alloy C96200			84.5 min.	9-11	1-1.8	1.5 max	0.3 max	1.0 max	0.03 max	-	0.1 max	
1	SK 2754*	70/30 Cu-Ni	65.3	31.3	1.04	1.09	0.49	0.68	0.009	0.014	0.01	0.004
3	SK 2754		Bal.	29.87	1.03	1.0	0.46	0.67	0.01			
4	SK 2757-2		66.84	29.93	1.1	0.96	0.41	0.64	0.01			
7	SK 2758		67.53	29.01	1.0	1.05	0.43	0.91	0.009			
10	SK 2759		68.15	29.4	0.94	0.63	0.45	0.97	0.006			
11	SK 2756		68.1	29.42	0.87	0.72	0.54	0.95	0.006			
12	SK 2757-1		69.88	26.92	0.94	0.91	0.38	0.84	0.005			
13	SK 2756		68.44	28.34	0.95	0.94	0.39	0.84	0.004			
14	SK 2755		68.46	28.75	0.5	0.93	0.41	0.83	0.001			
15	SK 2757-2		68.38	28.87	0.5	0.9	0.41	0.83	0.001			
ASTM B369-78 limits for alloy C96400			65 min.	28-32	0.3-1.5	1.5 max	0.5 max	1.5 max	0.03 max	-	0.15 max	

*CANMET Wet chemical analysis

Table 3. Risering system and casting quality in 90/10 and 70/30 Cu-Ni castings accepted for sea water.

Melt No.	Drawing No.	Fig. No.	Type of melt	Type of riser[a] and dimensions	Radiographic assessment (Numerical assessment according to ASTM E272)
3	SK 2754	5	70/30	Four blind risers and one open riser (1)	some shrinkage on mounting leg and inclusion in the body between nozzles (Level 2).
6	SK 2754	5	90/10	Four blind risers and one open riser (1)	some distributed porosity in cope half of flange (Level 1)
10	SK 2759	6	70/30	Four blind risers and one open riser (1)	- level 2 for flange and the body - some inclusion in feet of mounting leg
9	SK 2759	6	90/10	Four blind risers and one open riser (1)	- level 1 for flange and level 2 for the rest - only surface defects. Some inclusions in the body between the nozzles.
14	SK 2755	10	70/30	Two blind risers (2), four blind risers (1) and 2 open risers (3)	- level 1 for body and the nozzles and elbow neck - some inclusion in the cope half of flange near the riser location (Level 3)
17	SK 2755	10	90/10	Two blind risers (2), four blind risers (1) and 2 open risers (3)	- level 1 for 4 nozzles and the nearby body - level 2 for elbow neck - some inclusions in the cope half of flange near the riser location (Level 2)
7	SK 2758	12(a)	70/30	Four blind risers (1) and two open risers (1)	- level 1 for flange in drag half - level 2 for the rest (distributed micro-porosity in the body between nozzles and in flange near parting line)
8	SK 2758	12(b)	90/10	Four blind risers (1) and two open risers (1)	- level 1 for flange - level 2 for the rest (distributed shrinkage porosity in the body between nozzles)
11	SK 2756	11(a)	70/30	Two blind risers (2) connected to flange and two open risers (2) on top of flange and near one of the nozzles	- level 2 for body and the four nozzles - level 1 for flange in drag half. Some shrinkage in cope half of flange near riser location (level 3)

[a]Foseco insulating sleeves for all risers

1. 2.5 in (63 mm) diam x 4 in (102 mm) high
2. 3 in (76 mm) diam x 6 in (152 mm) high
3. 2.5 in (63 mm) diam x 5 in (127 mm) high

Table 3. (Cont'd)

Melt No.	Drawing No.	Fig. No.	Type of melt	Type of riser[a] and dimensions	Radiographic assessment (Numerical assessment according to ASTM E272)
13	SK 2756	11(b)	70/30	Two blind risers (2) connected to flange and two open risers (2) on top of flange and near one of the nozzles	- shrinkage in the body near riser location (level 4)
18	SK 2756	11(b)	90/10	Two blind risers (2) connected to flange and two open risers (2) on top of flange and near one of the nozzles	- some shrinkage porosity in the flange close to parting line and in the body close to flange (level 2)
19	SK 2756	11(b)	90/10	Two blind risers (2) connected to flange and two open risers (2) on top of flange and near one of the nozzles	- level 2 for flange, nozzles and the body - (some porosity near riser location in body and in cope half of flange)
12	SK 2757-1	9	70/30	Six blind risers (1) and two open risers (3)	- level 1 for both flanges - some inclusions in the body between nozzles (level 2 for body and the nozzles) - shrinkage at the junction between body and square mounting flange (level 3)
16	SK 2757-1	9	90/10	Six blind risers (1) and two open risers (3)	- some inclusion and gas porosity in one flange (level 2) - level 1 for body and the nozzles - some shrinkage at the junction between body and the square mounting flanges (level 2)
15	SK 2757-2	9	70/30	Six blind risers (1) and two open risers (3)	- level 1 for both flanges - some shrinkage in the square mounting flanges in the junction between the body and one of the circular flanges and th nozzle-body area close to riser location (level 2)
5	SK 2757-2	8	90/10	Five blind risers (1) and one open risers (1)	- level 2 for body and the nozzles - some shrinkage in cope half of each flange (level 2) - some shrinkage in the body-flange junction and between the square mounting flanges (level 3)

[a]Foseco insulating sleeves for all risers

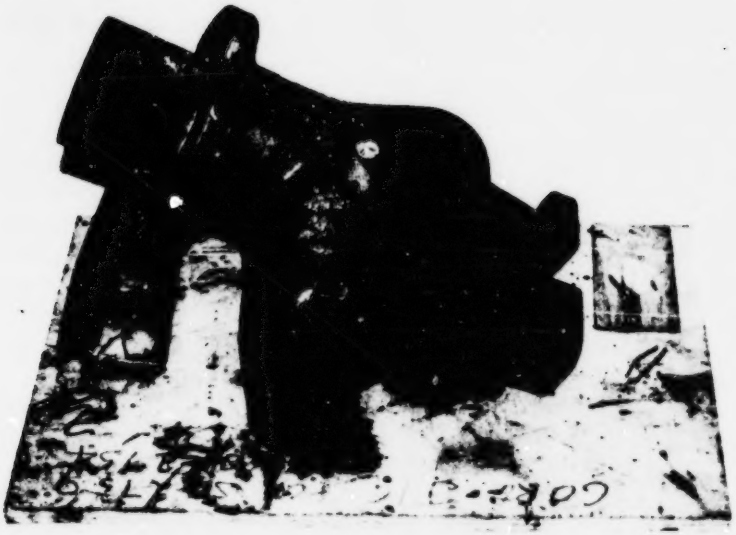
1. 2.5 in (63 mm) diam x 4 in (102 mm) high
2. 3 in (76 mm) diam x 6 in (152 mm) high
3. 2.5 in (63 mm) diam x 5 in (127 mm) high

Table 4. Tensile properties of test bars in 90/10 and 70/30 Cu-Ni alloys

Melt No.	Drawing No.	Type of melt	Wt% Si	Wt% Nb	UTS Ksi (MPa)	0.5% Yield strength Ksi (MPa)	El% in 2 in (51 mm)
5	SK 2757-2		0.16	0.4	51.1 (352)	29 (200)	22
6	SK 2754		0.17	0.18	54.9 (378)	32.6 (225)	24
8	SK 2758		0.14	0.32	53.7 (370)	32.4 (223)	25
9	SK 2759	90/10	0.12	0.32	48.8 (336)	25.6 (176)	27
16	SK 2757-1	Cu-Ni	0.21	0.35	54.4 (375)	32 (220)	31
17	SK 2755		0.16	0.27	50.3 (347)	25.8 (178)	34
18	SK 2756		0.18	0.40	50.1 (345)	32.7 (225)	29
19	SK 2756		0.19	0.20	55.9 (385)	34.4 (237)	29
ASTM B369-78 Specifications for alloy C96200			0.3 max	1.0 max	45 (310) min	25 (170) min	20 min
3	SK 2754		0.45	0.67	76.4 (526)	39.8 (274)	27
4	SK 2757-2		0.41	0.64	76.2 (525)	40.2 (277)	24
7	SK 2758		0.43	0.91	77.9 (537)	42.9 (296)	25
10	SK 2759	70/30	0.45	0.97	81.2 (559)	46.2 (318)	24
11	SK 2756	Cu-Ni	0.54	0.95	86.2 (594)	55.4 (382)	20
12	SK 2757-1		0.38	0.84	83.2 (573)	51.2 (353)	21
13	SK 2756		0.39	0.84	84.9 (585)	51.9 (358)	21
14	SK 2755		0.41	0.83	80.3 (553)	44.5 (307)	27
15	SK 2757-2		0.41	0.83	79.4 (547)	44.1 (304)	25
ASTM B369-78 Specifications for alloy C96400			0.5 max	1.5 max	60 (415) min	32 (220) min	20 min
4	Sk 2757-2* (Flange)		0.41	0.64	78.8 (543) 65.5 (451)**	45.4 (313) 42.2 (291)	21 17**

* 0.25 in. (6.3 mm) diameter

** defect in gauge section



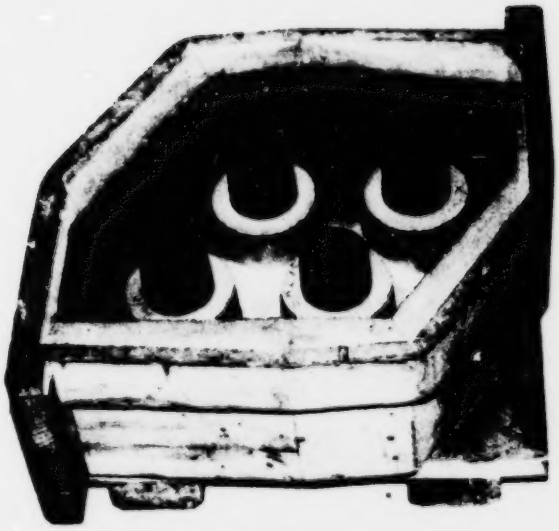
(a) SK 2754 (SK 2759 is identical but a mirror image.)

(b) SK 2755

(c) SK 2758

Fig. 1. Photographs of patterns.

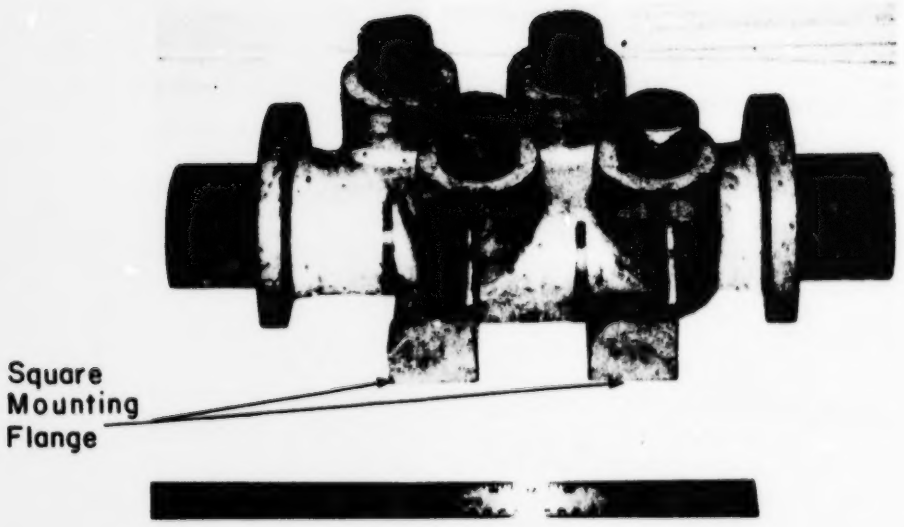
(d) SK 2756



(e) SK 2756

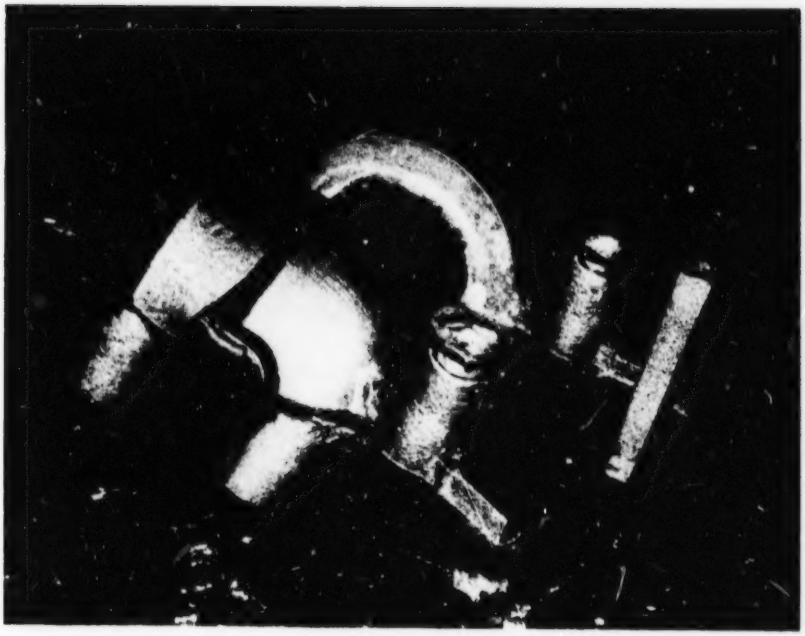
Fig. 1. Photographs of patterns.

(f) SK 2757-1 and SK 2757-2

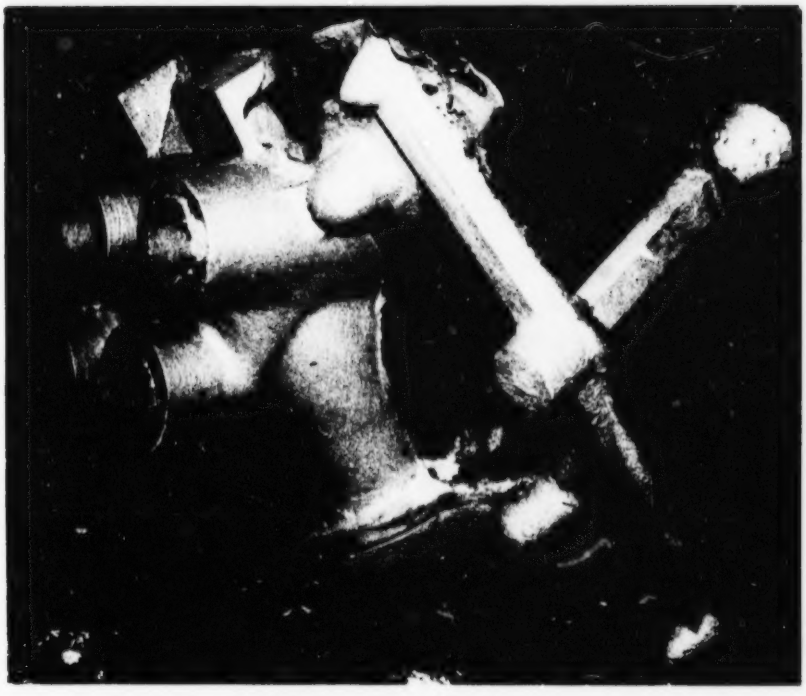


(g) SK 2757-1 (SK 2757-2 is identical except the location of the square mounting flange as shown in Fig. 3.)

Fig. 1. Photographs of patterns.

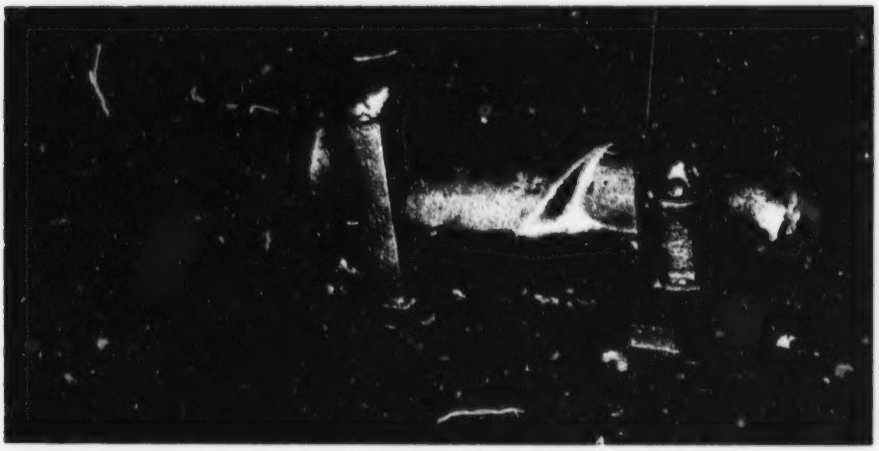


(a) Front

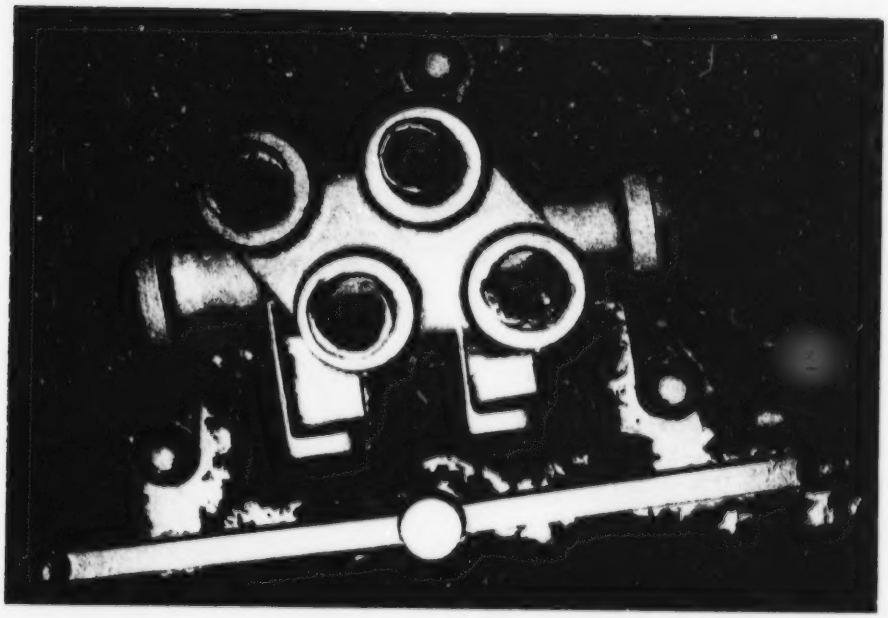


(b) Back

Fig. 2. Casting SK 2754 showing the gating and risering systems(melt No. 1).



(a) Front



(b) Back

Fig. 3. Casting SK 2757-2 showing the gating and risering systems (melt No.2).

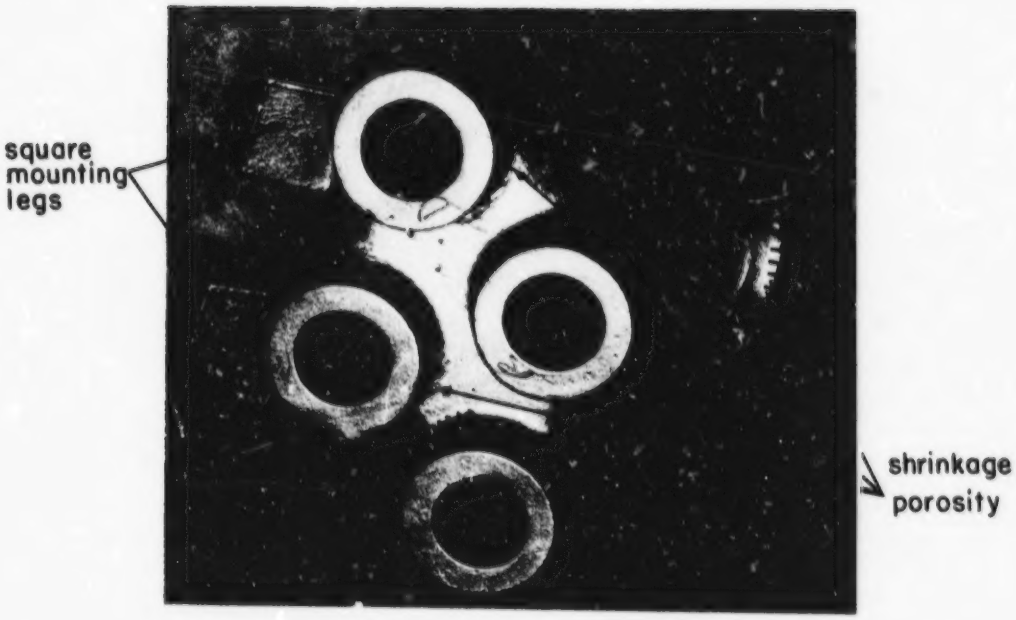


Fig. 4. Photograph of casting SK 2754 (melt No. 1) showing location of shrinkage porosity.

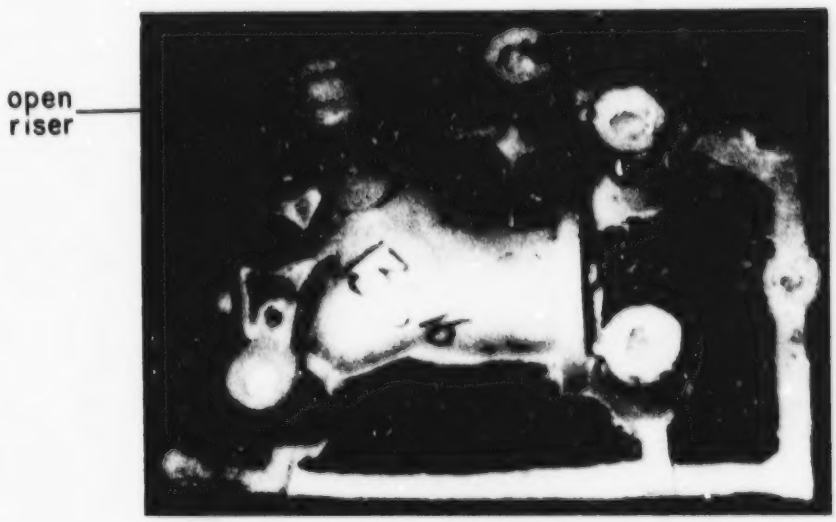


Fig. 5. Photograph of casting SK 2754 (melt No. 3) showing the revised gating and risering systems. (4 blind risers and one open riser). (neg 2764)

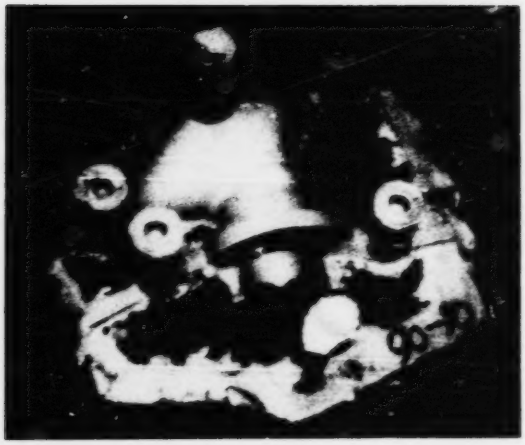
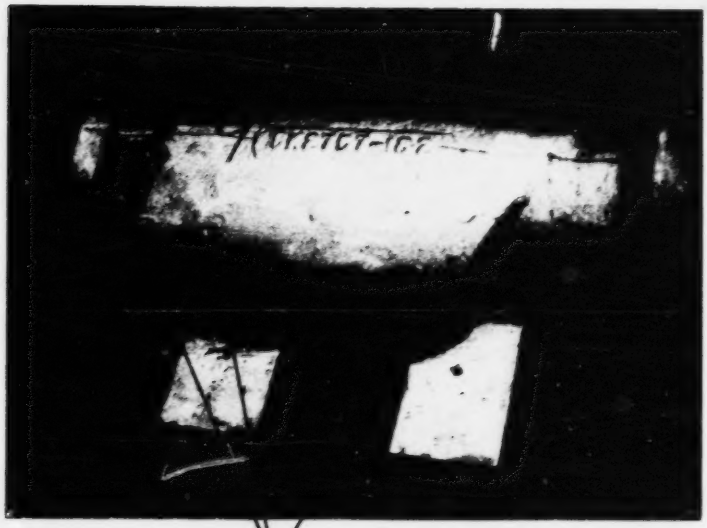
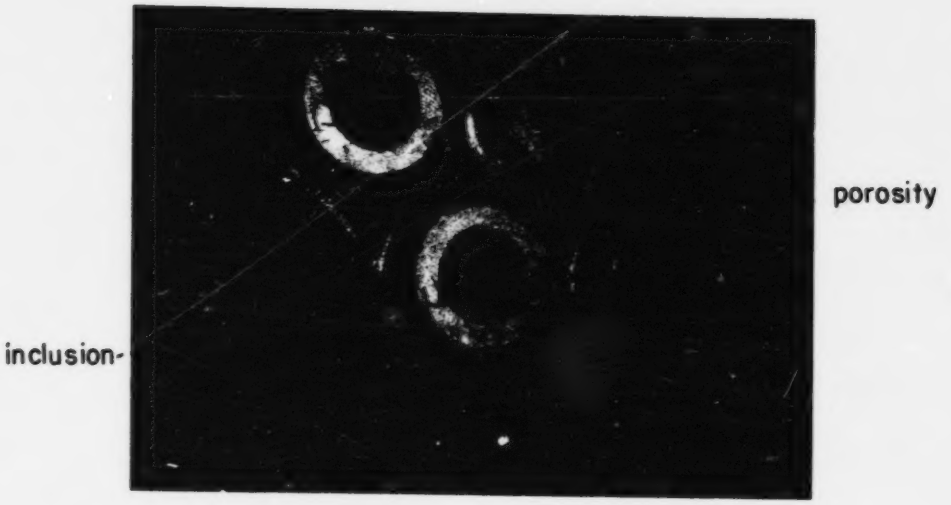


Fig. 6. Photograph of casting SK 2759 (melt No. 9) showing the gating and risering systems. (4 blind risers and one single riser). (neg 2919)



(a) Shrinkage porosity

Fig. 7. Photograph of casting SK 2757-2 (melt No. 2) showing location of shrinkage porosity and inclusions.



(b) Inclusions and porosity

Fig. 7. Photograph of casting SK 2757-2 (melt No. 2) showing location of shrinkage porosity and inclusions.

Fig. 8. Photograph of casting SK 2757-2 (melt No. 5) showing the modified gating and risering systems (5 blind risers and one open riser).

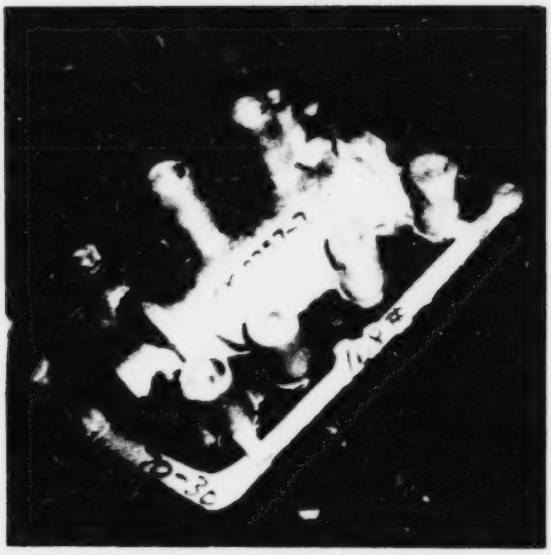


Fig. 9. Photograph of casting SK 2757-2 (melt No. 15) showing the modified gating and risering system (6 blind risers and 2 top risers). (neg 2921)

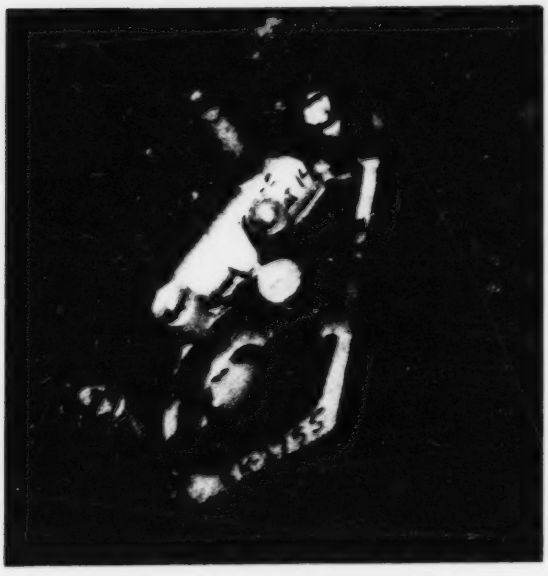
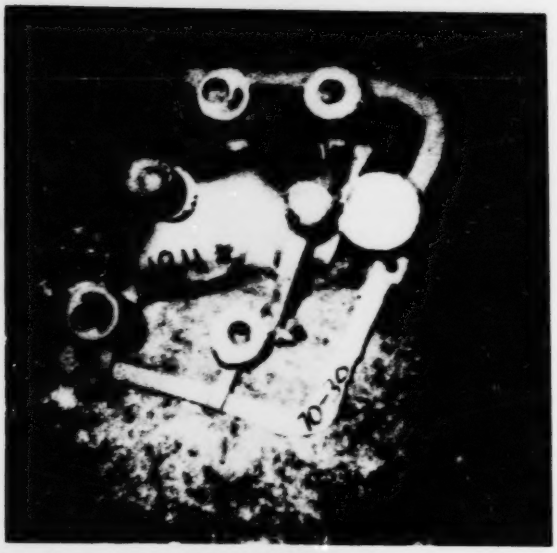


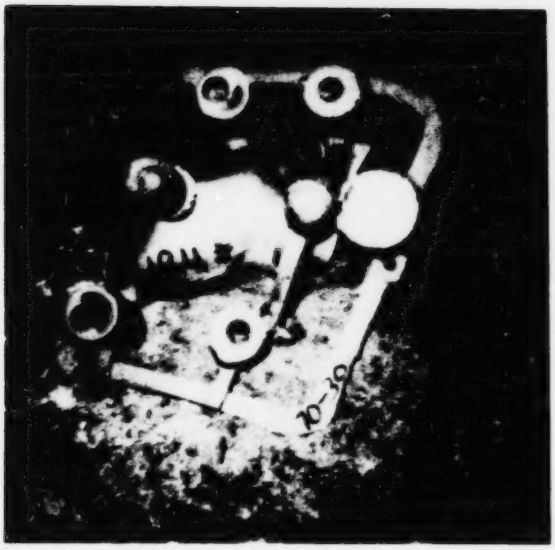
Fig. 10. Photograph of casting SK 2755 (melt No. 14) showing the gating and risering systems (6 blind risers and 2 top risers). (neg 2926)



(a) Melt No. 11, 70/30 Cu-Ni (neg 2924)

(b) Melt No. 13, 70/30 Cu-Ni (neg 2925)

Fig. 11. Photographs of casting SK 2756.

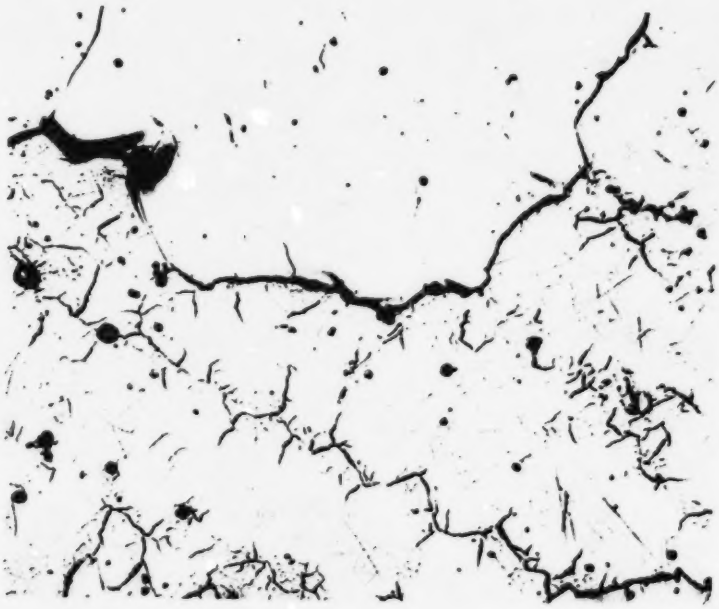


(a) Melt No. 7, 70/30 Cu-Ni (neg 2918)

(b) Melt No. 8, 90/10 Cu-Ni (neg 2922)

Fig. 12. Photographs of casting SK 2758

(a) 90/10 Cu-Ni, melt No. 16 (neg 3550)



(b) 70/30 Cu-Ni, melt No. 2 (neg 3551)

Fig. 13. Optical micrographs of 90/10 and 70/30 Cu-Ni alloys. Alcoholic ferric chloride etch. (200X)